

EAVE System Modifications  
for  
Operational Evaluation in Hostile Environments

Final Report

December 30, 1983

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EAVE SYSTEM MODIFICATIONS FOR OPERATIONAL EVALUATION IN HOSTILE  
ENVIRONMENTS

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1.0 INTRODUCTION

An operational evaluation of the EAVE-East vehicle and its systems was proposed in order to demonstrate the potential of the technologies associated with the vehicle. This report covers Phase I which had as its objectives:

1. To understand the impact on the vehicle's navigational capability operating within a complex underwater structure by including (1) the added computational requirements required of its more complicated configuration and (2) the impact on system performance of the subtle geometrical inconsistencies of a real-world structure.
2. To modify the vehicle parameters and system configuration as necessary to allow an operational evaluation of the system around a defined underwater structure.
3. To understand the impact of the salt water versus fresh water environment on the EAVE vehicle system.

1.1 PROJECT RESULTS

The completion of this project has resulted in:

1. Development of a test plan defining the proposed Phase II testing.
2. Modification of the applications programs required to perform an inspection mission around the proposed Fisher Island structure.
3. Completion of necessary vehicle hardware modifications required for the proposed testing.

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Note: A description of the EAVE vehicle and its performance is described in Appendix A.

## 2.0 TEST PLAN FOR OPERATIONAL EVALUATION

### 2.1 The Structure

The structure proposed to us is a navigational tower east of Fisher Island in Miami, Florida. The tower is in 23 feet of water. The bottom is coral. The currents in the area vary from calm at slack tide to approximately 1.5 knots maximum during tide changes.

The tower has four legs constructed of 12 inch diameter pipes located approximately at the corners of a 20 foot square. The tower rises out of the water approximately 30 feet. The structure has several cross members. (See Figure 1 for details.)

Following is a path profile, mission scenario and command list designed to demonstrate the EAVE vehicle's a) precision acoustic navigation system, b) self control response and stability, c) ability to store and return all data pertinent to the mission, d) ability to go to predesignated locations and hover at those points for a fixed period of time, e) ability to return to a predesignated location with one foot accuracy, and f) demonstrate completely autonomous untethered behavior.

### 2.2 Mission Outline

The EAVE vehicle is approximately 5.5 feet high and 4.5 feet wide. The proposed path profile (Figure 2) for the mission is plotted for the center of the vehicle, hence, at any particular point in this plot, the vehicle is actually 2.25 feet closer to structure members than the plot indicates. At inspection points F, H and N, the front of the vehicle is approximately one foot from the structure.

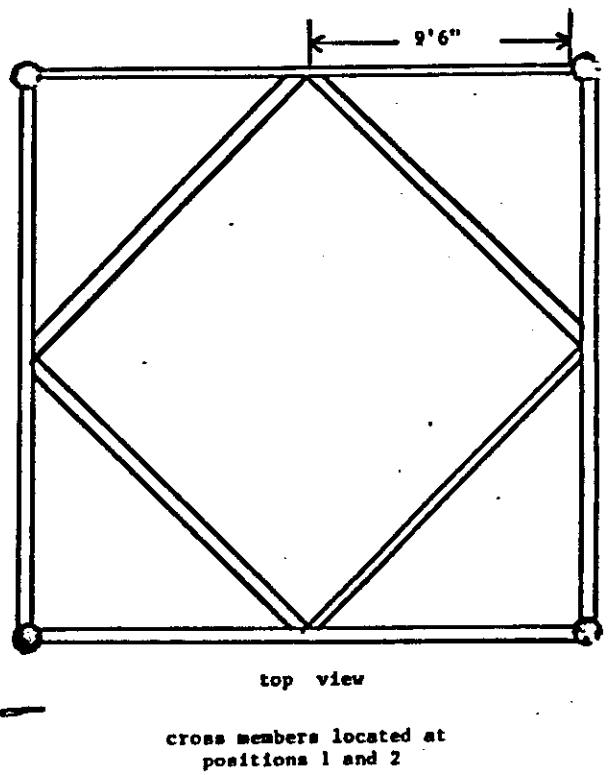
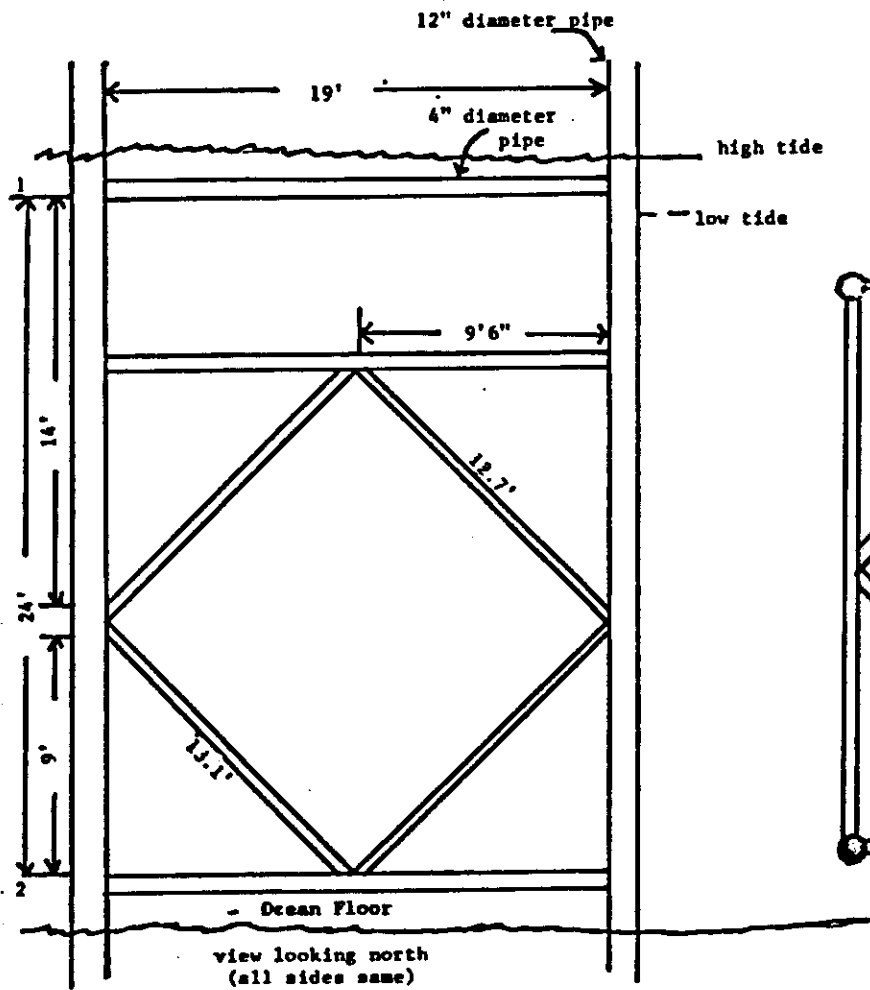


FIGURE 1

[illegible]

**Legend:** F = Forward  
B = Back up  
SL = Slide left  
SR = Slide right  
**Example:** F + 15 = Forward 15 feet

**FIGURE 2**

The path that the vehicle takes to arrive at point A (start) in the plot will be determined on site, and obviously depends on where the launch barge is anchored. Several commands in the command list (Figure 3) have purposely been left blank to allow for the vehicle to get to and return from the start point.

The small arrows in Figure 2 along the path indicate the heading of the bow of the vehicle while the larger arrows indicate the vehicle path in two dimensions. The locations on the structure designated by an "X" are points at which the vehicle will move to within one foot of the structure.

A three dimensional view of the path is presented in Figure 4. Notice however, that some of the front and back plane diamond-shaped structure elements are not shown in order to more clearly demonstrate the vehicle path.

The mission starts at point A. The exact path of the vehicle to point A from the launch barge will be input on site. The vehicle first centers itself on the structure opening (Command 5) and orients itself such that the bow is pointing perpendicular to the face of the structure. Next (Command 6), it moves forward through the diamond shaped beams to the center of the structure. The following command (7) makes the vehicle slide right while maintaining its heading and depth. It then (Command 8) climbs to a depth which puts the center of the vehicle at the same depths as the point X to be inspected. It then moves forward to point E, and then moves slowly forward to point F which places the bow of the vehicle at one foot from the inspection point, later it backs up to point F. Next the vehicle will slide left across the structure while maintaining two feet

Command Number	Command Type	IGN x,y	Duration (sec/hundred)	x (ft)	y (ft)	z (ft)	x (ft/sec)	θ (rad)	θ (rad/sec)	
1	} Commands to go from launch point to point A on Path Profile.									
2										
3										
4										
turn 90° at A	5	rotate	false	6000	10.0	-5.0	12.0	1.0	1.57	.225
A to B	6	horiz_move	false	6000	10.0	10.0	12.0	1.0	0	.225
B to C	7	horiz_move	false	6000	5.5	10.0	12.0	1.0	4.71	.225
C to D	8	vert_move	false	6000	5.5	10.0	7.5	1.0	1.57	.225
D to E	9	horiz_move	false	6000	5.5	15.5	7.5	1.0	0	.225
E to F	10	horiz_move	false	3000	5.5	16.5	7.5	1.0	0	.225
F to E	11	horiz_move	false	3000	5.5	15.5	7.5	1.0	3.14	.225
E to G	12	horiz_move	false	6000	14.5	15.5	7.5	1.0	1.57	.225
G to H	13	horiz_move	false	3000	14.5	16.5	7.5	1.0	0	.225
H to G	14	horiz_move	false	3000	14.5	15.5	7.5	1.0	3.14	.225
G to I	15	vert_move	false	6000	14.5	15.5	12.0	1.0	1.57	.225
rotate at I	16	rotate	false	6000	14.5	15.5	12.0	1.0	0	.225
I to J	17	horiz_move	false	6000	10.0	14.5	12.0	1.0	1.57	.225
J to K	18	horiz_move	false	6000	27.0	10.0	12.0	1.0	0	.225
K to L	19	horiz_move	false	6000	27.0	-5.0	12.0	1.0	1.57	.225
turn at L	20	rotate	false	6000	27.0	-5.0	12.0	1.0	1.57	.225
L to M	21	horiz_move	false	6000	20.0	-5.0	12.0	1.0	4.71	.225
M to N	22	horiz_move	false	3000	20.0	-4.0	12.0	1.0	0	.225
N to O	23	vert_move	false	3000	20.0	-4.0	8.0	1.0	1.57	.225
O to N	24	vert_move	false	3000	20.0	-4.0	12.0	1.0	1.57	.225
N to M	25	horiz_move	false	3000	20.0	-5.0	12.0	1.0	3.14	.225
rotate at M	26	rotate	false	6000	20.0	-5.0	12.0	1.0	3.14	.225
M to A	27	horiz_move	false	6000	10.0	-5.0	12.0	1.0	0	.225
28	} remaining commands to get back to launch point									

\*note: a) Vehicle x, y position is at center of transmitter triangle on vehicle.  
b) Vehicle depth is at top of vehicle transmitters. (Can easily be offset to other position.)  
c) Horiz\_move commands: Bearing is relative to vehicle. Forward = 0  
Backward = 3.14 (180°)  
Slide left = 1.57 (90°)  
Slide right = 4.71 (270°)

FIGURE 3. Command list for inspection mission at navigation tower off Fisher Island.



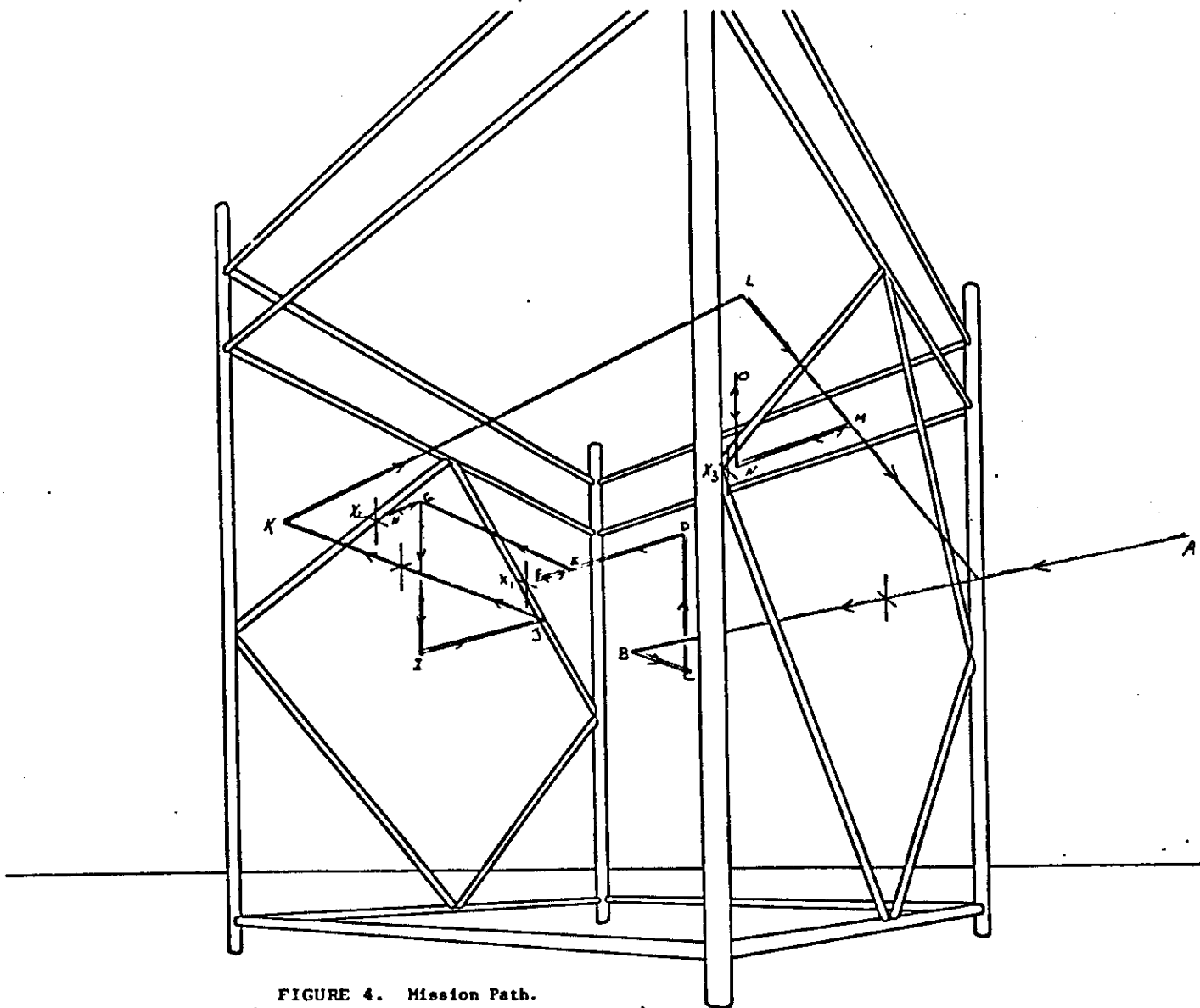


FIGURE 4. Mission Path.  
(note: not all structure members shown)

from the plane of the structure wall to point G. It then moves to within one foot of the inspection point X, and then back to G. Next it dives to point I and rotates 90<sup>2</sup> degrees counterclockwise. The vehicle then slides left to point J where it should be centered on the exit diamond-shaped structure opening and (Command 18) proceeds out the structure where it performs several more maneuvers to arrive at point N. At this point, the vehicle moves vertically up the pipe, holding bearing and x, y position while remaining one foot from the beam. It then descends in the same manner to point N. The following command (25) instructs the vehicle to back up to point M and (Command 26) turn 90 degrees to face the start point A. The commands to have the vehicle return to the barge will be inputted on site.

It will be noticed that the position coordinates are all referenced to the structure. It is a simple matter, once the transponders are placed on site (in the ocean), to translate and rotate these coordinates to that of the transponder baseline.

The mission described above lasts approximately 19 minutes plus the time to go to and from the start point. This time is primarily governed by the duration input for each command. If this duration is made very small (i.e. smaller than the time required to swim the path) the mission time would be governed by the amount of time that the vehicle requires to actually swim the path and acquire all coordinates within  $\pm 1$  foot and  $\pm 6$  degrees. Both of these tolerances can be easily changed between missions if that is desired. If the duration were set very small, this mission would probably take eight to ten minutes.

At the end of each day's testing, the Magnetic Bubble Memory

(MBM) computer will be removed from the vehicle. A plot of time versus the vehicle's x, y, z position and bearing ( $\theta$ ) will be made at 1.5 second intervals for the day's testing. (This takes about 1.5 hours.) A complete readout of the MBM data will also be stored on a floppy disc for future analysis. At this point, the MBM is erased and ready for the next test day.

### 3.0 VEHICLE MODIFICATIONS

Several modifications to the vehicle systems have been accomplished. A few software parameter adjustments will be made on site.

Some of the system modifications are listed here.

1. A spare set of batteries has been constructed which will allow for the vehicle to be operational for twice its normal period in any given day when required.
2. Protective cages or screening for the thruster propellers, vehicle transducers, and battery cable are required for safety.
3. Auxiliary eight volt computer memory protection batteries will be implemented to allow for system battery changes in the field. A system battery change requires approximately ten minutes.
4. Minor adjustments to the vehicle ballast weights will be accomplished at the site to account for salt water buoyancy. This will require only a few minutes the first day on site.
5. A redundant bearing calculation will be determined from existing navigation data. The software is written and need only be implemented. The data required is already being acquired by the navigation computer.
6. The software changes which account for speed of sound in the area of interest will be made and compiled prior to the trip to Florida.
7. A new solid state compass was purchased and is currently in use on the vehicle. It provides for instantaneous vehicle bearing and has an accuracy of  $\pm 1$  degrees.
8. The mission scenario or applications program has been written and will be downloaded into the 68000 computer on site.

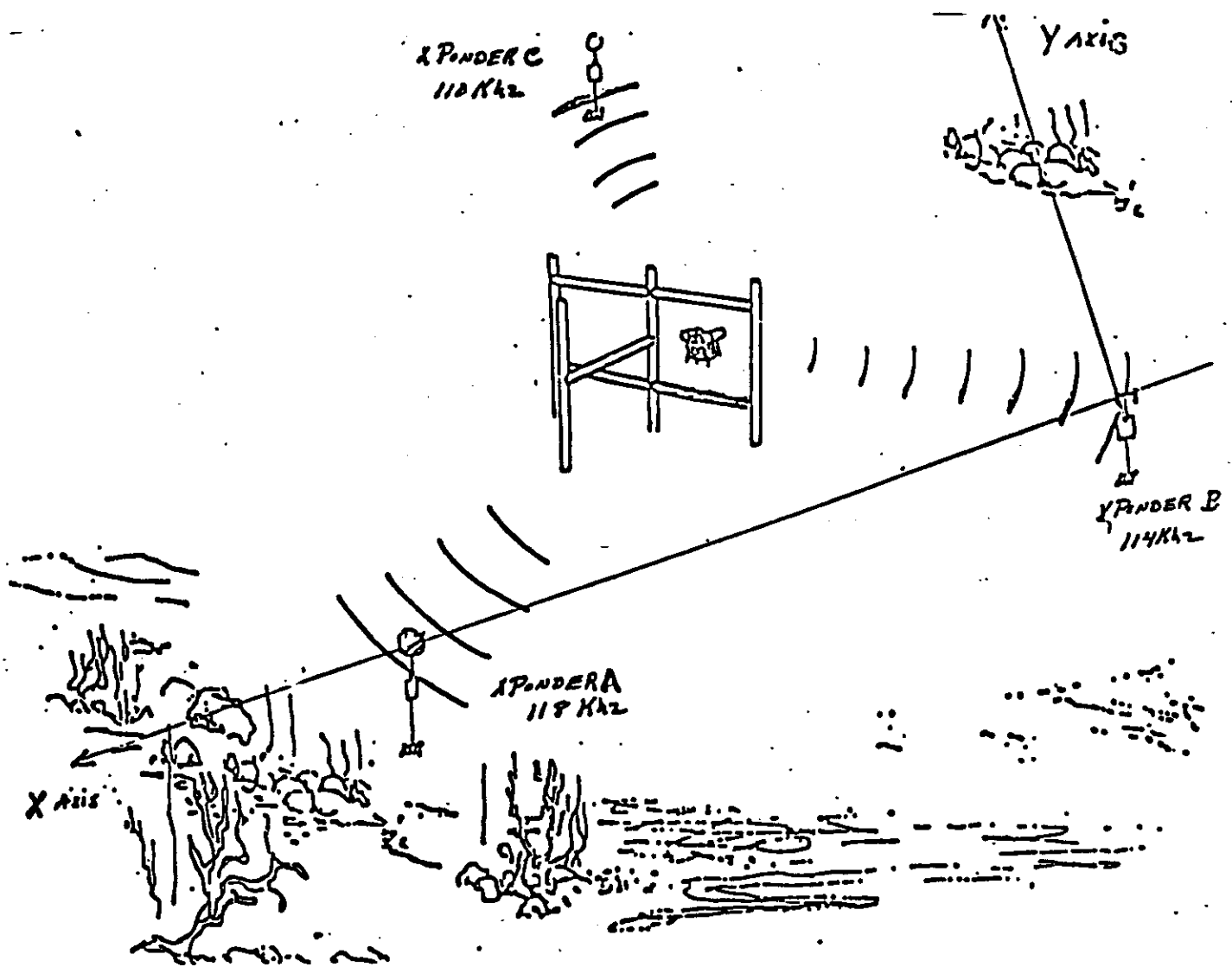


FIGURE 5.

#### 4.0 TEST OUTLINE SCHEDULE (Prior to conducting inspection mission.)

Day 1: Assemble complete vehicle system on land. Note: The vehicle will in all probability be shipped to Miami disassembled.

- Check out computers, compass, pressure transducer, thrusters, etc.
- Run all programs to verify system integrity.
- A checklist of procedures will be followed to assure system integrity is verified.

Day 2: At structure location on barge (divers required):

- 1) Calibrate turnaround times of each transponder.
- 2) Anchor 3 transponders at depth of 12 feet in approximate configuration of Figure 5.
- 3) Place vehicle in water on tether.
  - a. Adjust variable buoyancy weights.
  - b. Calibrate pressure transducer.
  - c. Test navigation system.
  - d. Test thruster response.
- 4) Acoustically measure the exact location of the transponders through the use of the vehicle's Self-Calibrating Algorithm.
- 5) Acoustically measure the position of the structure in reference to the transponder array baseline.
- 6) In Lab:  
Input the transponder net parameters, relative structure coordinates, and calibrated transponder turnaround times into vehicle program.

Day 3: On barge:

- 1) Load all system programs.
- 2) Calibrate pressure transducer for daily variation.
- 3) Place vehicle in water on tether.
- 4) Run vehicle maneuver tests tethered.
- 5) Run vehicle maneuver tests untethered.
- 6) Adjust control gains if necessary.

#### 4.1 INSPECTION MISSION OUTLINE/SCHEDULE

Once the vehicle system and transponder net are calibrated and ready to conduct an inspection mission. The tests will proceed in the following manner.

The first inspection mission will be conducted with divers in the water to provide a visual report of performance for the project engineer. The MBM recorder data will be plotted and printed out for analysis to verify vehicle performance is adequate.

When the project engineer is satisfied that the vehicle is performing normally, a 16mm documentary film will be made of the complete mission from launch to retrieval. This film coupled with the complete mission profile and data analysis will form the substance of vehicle performance results.

Assuming decent weather and no significant, major systems problems, the above work could be completed in one week. The overall testing time period would thus require two weeks.

## Appendix A

### 1. DESCRIPTION OF EAVE VEHICLE SYSTEM ELECTRONICS

#### General Systems Interrelationships and Operation

The EAVE vehicle is shown in Figure 6. A block diagram of the computer subsystem interaction is shown in Figure 7. The system architecture is one of distributive processors, each of which has its own functions to perform (Tables 1,2,3,4). Many of these functions are performed simultaneously. The critical computer which makes major decisions and controls the overall vehicle performance is the 68000 command computer. The command computer communicates with all of the vehicle sensors and computer systems.

The general timing for the system is shown in Figure 8. A cycle time for the system is the time it takes for the 68000 command computer to acquire all the data from sensors and computers, perform its calculations, make its decisions regarding where it is, where it wants to go and how to get there, and send its commands. The present system operates at a cycle time of approximately 1.5 seconds.

During one cycle period, the command computer reads pressure to determine depth (z), reads the compass to determine bearing ( $\theta$ ) reads the navigation computer to acquire new range data and the vehicle x, y position. It then translates this position to the center of the vehicle, and computes changes in  $\theta$ , x, y, z, and time (t).



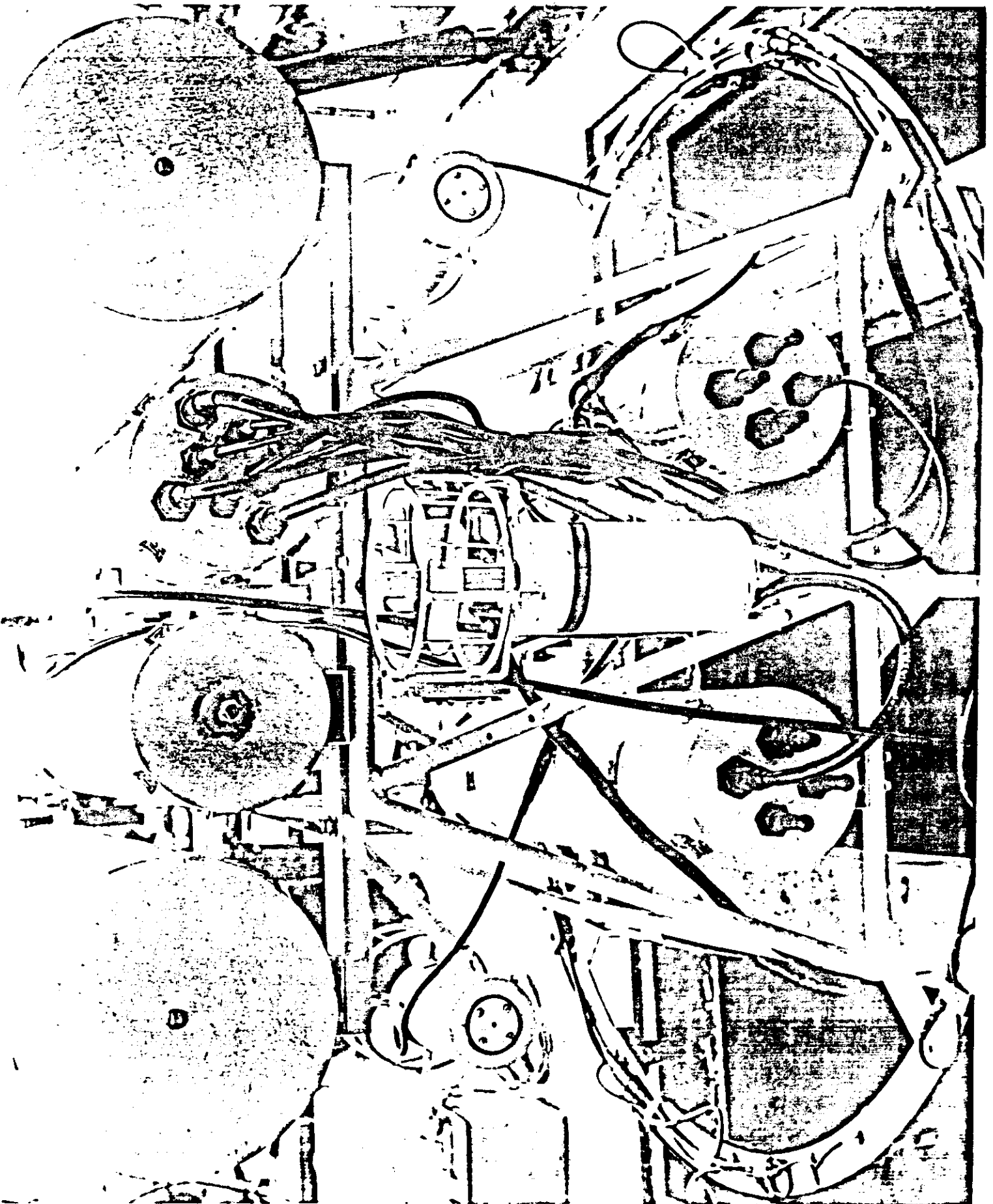


FIGURE 6. EAVE.

Block Diagram of Vehicle Systems

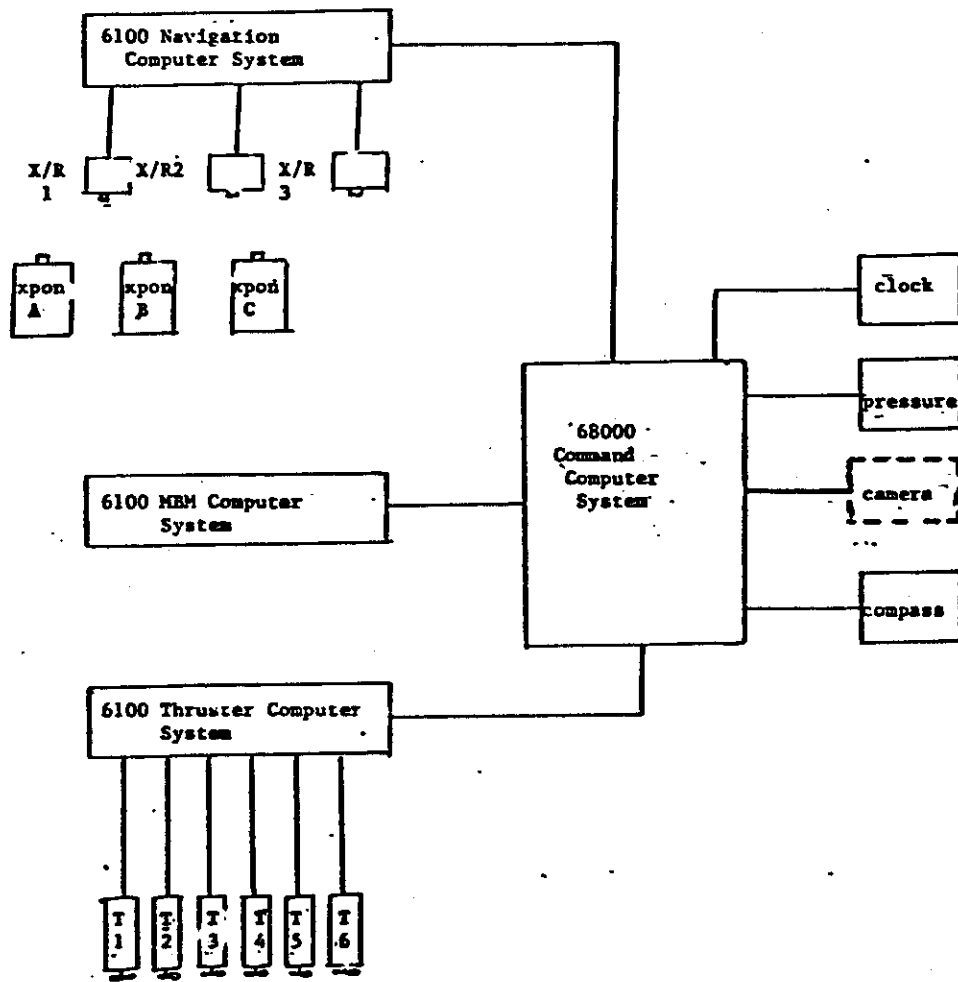


FIGURE 7

TABLE 1

68000 COMMAND COMPUTER FUNCTIONS

- Maintains time clock
- Reads pressure and calculates depth (z)
- Reads compass and computes relative bearing ( $\theta$ )
- Requests x, y position from navigation computer and translates it to center of vehicle
- Computes changes in:  
time, x, y, z and  $\theta$
- Decides how to control thruster motors in order to perform a list of movement commands (such as SIMS mission)
- Passes data to Magnetic Bubble Memory (MBM)

TABLE 2

NAVIGATION COMPUTER SYSTEM FUNCTIONS

- Keys 95kHz transmitter on vehicle
- Receives and counts total time to each transponder and back (nine 12 bit words)
- Requests and receives vehicle depth (z) from Command Computer
- Calculates x, y position of transmitter on vehicle in its math processor
- Passes all above data to command computer upon request

TABLE 3

MAGNETIC BUBBLE MEMORY SYSTEM FUNCTIONS

- Stores mission data from command computer upon request.
- 1.024 Mbit data storage capacity and an additional 2% for file overhead
- Maintains file system which contains 20 files each with 50 block capacity. Each block contains 128 bytes. Files can be addressed in random access.
- Allows for post-mission analysis (i.e. reconstruction of mission parameters).

**TABLE 4**

**THRUSTER COMPUTER SYSTEM FUNCTIONS**

- Turns on vehicle thrusters in proper direction and at proper speeds upon request from command computer

# EAVE VEHICLE PROCESSOR TIMING

TIME	CYCLE 1							CYCLE 2		CYCLE 3	
COMMAND COMPUTER	READ PRESSURE	READ COMPASS	READ NAV	TRANSLATE X Y Z	COMPUTE $\Delta\theta$ $\Delta X$ $\Delta Y$ $\Delta Z$ $\Delta t$	DECIDE BASED ON MISSION	COMMAND THRUSTER COMPUTER	REPEAT		REPEAT & STORE ALL DATA FOR 3 CYCLES IN MBM	
NAV COMPUTER	X MIT, RECEIVE CALCULATE X, Y				REPEAT			REPEAT	REPEAT	REPEAT	REPEAT
THRUSTER COMPUTER	TURN ON SELECTED MOTORS AT PROPER SPEEDS IN PROPER DIRECTION AS DETERMINED BY COMMAND COMPUTER.							REPEAT		REPEAT	
COMPASS	READ BEARING	REPEAT	10 PER CYCLE					REPEAT		REPEAT	
PRESSURE	READ PRESSURE	REPEAT	10,000 PER CYCLE					REPEAT		REPEAT	
MBM	SLEEP									→ STORE DATA IN MBM	

FIGURE 8

The 68000 computer then looks at its command list for the particular mission. It determines where it is going compared to where it is and issues appropriate instructions to the thruster computer to perform the maneuvers necessary to keep it on course. After the commands are issued the 68000 computer continues to repeat these functions.

At the end of every third cycle the command computer sends 128 bytes of data to the Magnetic Bubble Memory (MBM) computer for storage. The data consists of all essential information gathered during the three previous cycles as well as the instructions sent by the command computer. This data makes a complete mission analysis possible after the fact, and allows the operator to replot the vehicle path and compare vehicle commands to actual vehicle performance.

The MBM is a nonvolatile high density data storage system. The present configuration has a 1 megabit data storage capacity. A 6100 computer controls the MBM device, receives and/or transmits data and provides the file management for the data. For a Structural Inspection Mission System (SIMS) mission, the data is stored in time sequence such that the first data word of each data cycle is the actual mission time. For each data cycle (command computer cycle time) the data stored is that shown in Table 5. Whenever the MBM is not active the 6100 computer puts the MBM to sleep to conserve power.

The navigation computer has a cycle rate which can be varied in software. For the inspection mission it operates at a speed of 0.4 seconds. During the navigation cycle the navigation system selects a transmitter, sends out an interrogate pulse at



## DATA FORMAT FOR ONE COMMAND COMPUTER CYCLE

<u># of Bytes</u>	<u>Designation</u>	<u>Information Description</u>
2	+	Mission time in hunderdths of a second
2	x	x Position calculated from nav. (counts)
2	y	y position calculated from nav. (counts)
2	z	depth calculated from pressure (binary)
2	translation x	x position translated to center of vehicle (binary)
2	translation y	y position translated to center of vehicle (binary)
2	translation z	z poition translated to pinger depth (binary)
2	θ	bearing in degrees
2	reference word	transmitter, record for calculation, calculate yes/no, past history
(18)	RDM	Ram Data Matrix (counts)
(6)	thruster	thruster polarity, speed for each thruster
<hr/> 42 Total Bytes		

95kHz and receives nine return signals, three from each transponder (see typical transponder configuration in Figure 4). It then determines which data to use, acquires a depth (z) from the command computer and uses its math processor to calculate an x, y position. It then continuously repeats this cycle. Whenever the command computer interrupts the navigation computer the navigation computer sends the nine return signal counts, the calculated x, y position and a reliability word.

The function of the thruster computer is to control the six thruster motors on the vehicle. The thruster computer can address any or all thrusters and select any one of 31 speeds in either the forward or reverse thrust direction for each thruster. The thrusters are oriented on the vehicle as shown in Figure 9.

The thruster computer makes no decisions, it merely carries out the commands sent to it by the 68000 command computer.

#### Overall Vehicle System Software

The software required (see software block diagram Figure 10) to make the subsystems perform interactively consists of a series of device handlers, individual computer operating systems (i.e. navigation, MBM, thruster), a vehicle operating system and an assortment of routines directly related to vehicle control for particular vehicle missions (i.e. mission scenarios, control dynamics, etc.).

# Thruster Motor Orientation on EAVE Vehicle

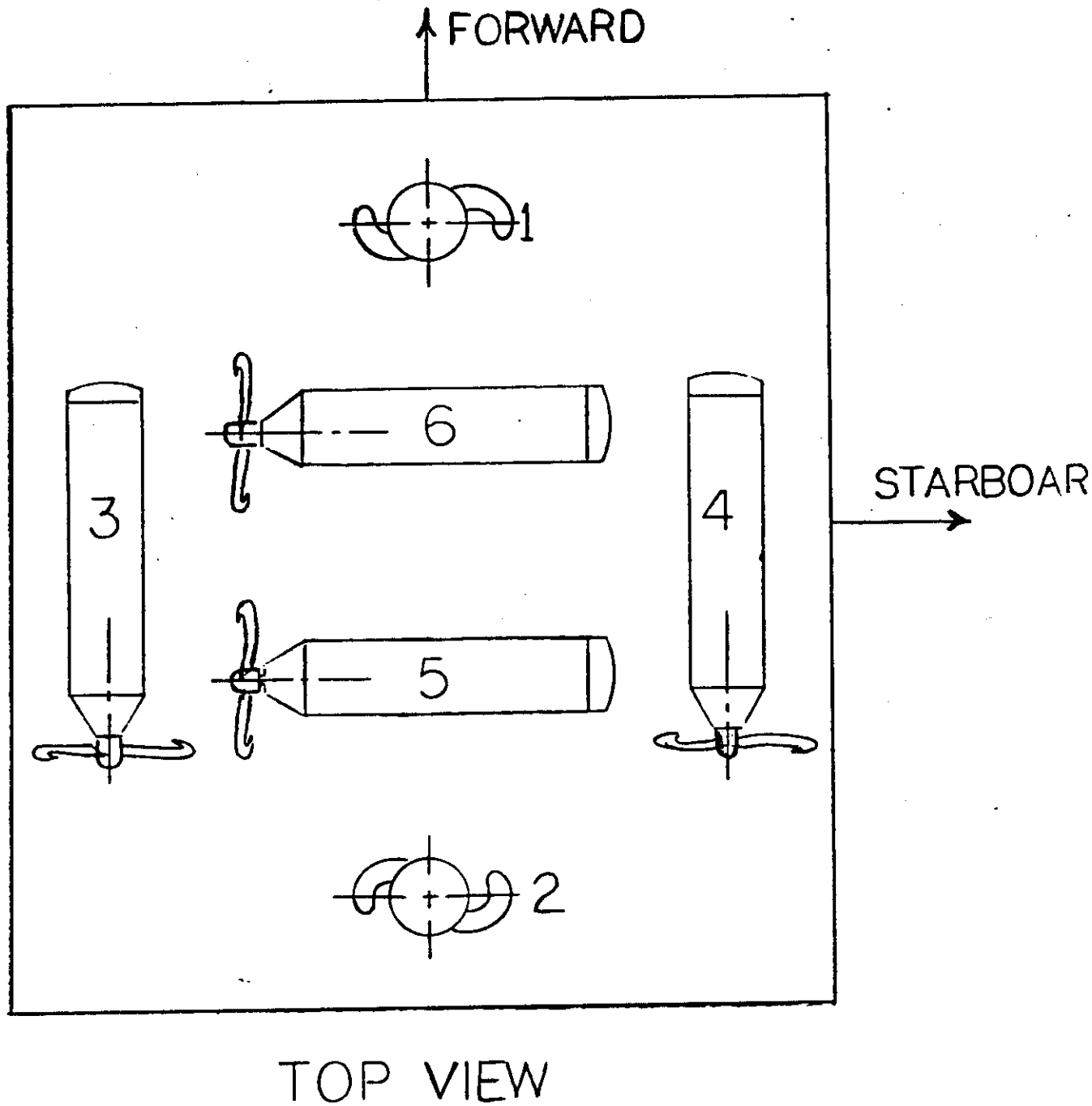


FIGURE 9

Vehicle Software Diagram

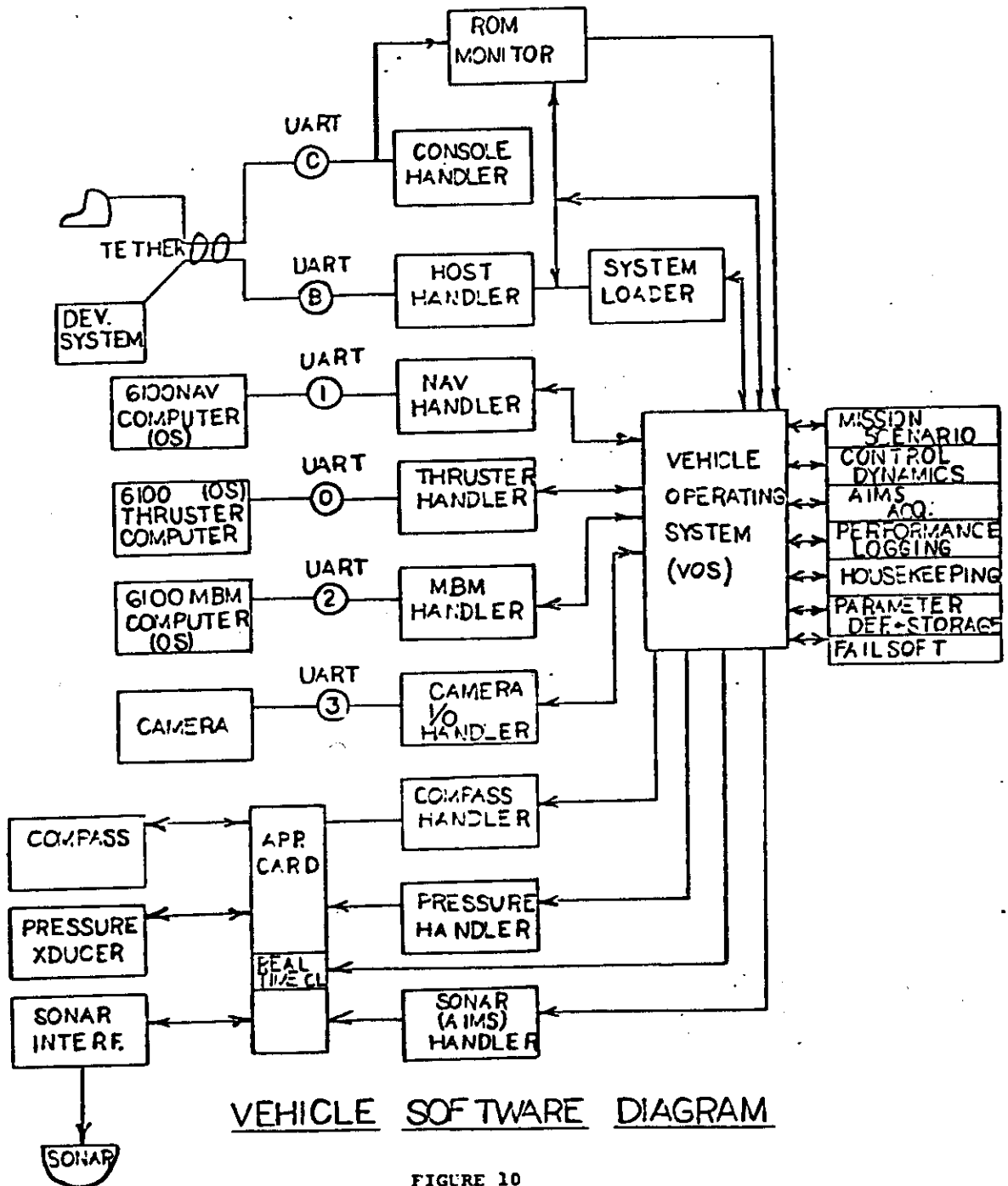


FIGURE 10

The individual computer operating systems (navigation, MBM, thruster) are the software which allows each computer system to stand alone in terms of performing its own specific task. For example, the navigation computer software allows the 6100 computer to:

1. Control timing for the transmitters and receivers.
2. Read the counts for range measurement.
3. Assign a weighted value of "goodness" to these counts.
4. Decide which counts to use in calculating and x, y, position.
5. Manipulate the math processor to calculate the x, y, position.
6. Store the required information in memory.
7. Transfer the data to the command computer upon request.

The individual operating systems for these computers (6100) are written in assembly language, and will in all probability not change very much, if at all. The exception is that a new 68000 based navigation system is being designed for long range navigation and will be programmable in high level language.

There are several "handler" routines written to communicate with each vehicle subsystem. The handlers are really the software interface between each vehicle component and the vehicle operating system. These handlers are all written in high level "C" language.

The vehicle performance programs include:

1. A routine which performs dynamic feedback control functions for the vehicle system.
2. The mission scenario strategy.
3. Sonar acquisition routine.

4. Data logging for storage in the MBM.
5. Housekeeping.
6. Parameter definition and storage.
7. Fail soft routines.

All of these programs are written in high level "C". The sections to be changed for different missions would be the mission scenario strategy and the parameter definition and storage routines.

The central nervous system of the vehicle is the vehicle operating system (VOS). It serves to integrate all the vehicle subsystems into a unified whole vehicle. It is the hub of the vehicle system and is also written in "C" language.

#### Summary of Electronic System Results

Tests were conducted at Mendum's Pond in Barrington, NH from May to November in 1983. This section presents a brief executive summary of results of the vehicle systems as of this time (November 1983).

- A. The thruster computer and thrusters operate reliably. The vertical thruster pair was fitted with counter-rotating propellers in order to reduce a tendency for the vehicle to rotate due to precession when both propellers were of the same type. The results were very dramatic and generated significant savings in power previously required to maintain vehicle heading.
- B. The navigation computer system provides for position accuracy of 8 inches for the inspection type geometry and maintains an x, y position over time to within 4 inches.

A position jitter or shift occurred when switching between transmitters on the vehicle. This is attributable to the transponders not being exactly at the positions provided to the computer. This jitter should be corrected when the self calibration algorithm is perfected.

Another error occurred on occasion. Due to the variable window strategy used in the navigation algorithm, it is

possible for the system to occasionally read a count due to multipath as a good count and hence calculate an erroneous position. In order to discriminate against this occasional gross error in the navigation computer, a simple predictor algorithm was written for the command computer which recognizes gross position jumps as physically impossible. It does not act on them and requests a new calculation from the navigation computer.

- C. The 68000 command computer has performed very reliably over the past year. It is currently operating at a speed of 1.5 seconds per cycle (i.e. complete system update and command execution). This speed should be further reduced to approximately 1 second per cycle once the navigation system has been set up as a separate task function. The thruster computer and magnetic bubble memory computer are already running as separate tasks. The navigation computer tasking is presently underway and should be completed by mid-December.

Use of the 68000 computer has allowed the writing of sophisticated and complex programs in "C" language in a very short time. Program debugging and changes are very easily managed.

- D. The magnetic bubble memory system has also been functioning very well. It has been used consistently to acquire field data on untethered missions and has allowed us to completely reproduce and analyze vehicle performance in the laboratory after each mission.

A plotting program was written and is used in data analysis which allows us to plot 1 megabit of data in approximately 1 1/2 hours. A complete listing of data is also made for every mission. A minor program bug was found in the 68000 software which communicates with the MBM computer. This is currently being corrected.

- E. The final phase of system testing prior to actually sending the vehicle on a complex mission consisted of preprogramming the vehicle to perform certain maneuvers while recording vehicle behavior (in the form of data). The purpose of these tests was to determine the proper gain constant settings in the software feedback control loops. The control algorithm (residing in the 68000 computer in "C" language) is the heart of the vehicle maneuvering system for any type of mission.

Once the proper gain constants were determined the vehicle characteristics were as follows:

	Overshoot (maximum)	Maneuvering	Station Keeping
Depth Accuracy (z)	1.5 ft.	$\pm 3$ in.	$\pm 3$ in.
Position Accuracy (x,y)	1.5 ft.	$\pm 12$ in.	$\pm 5$ in.
Bearing Accuracy ( $\theta$ )	20 degrees	$\pm 15$ degrees	$\pm 6$ degrees

F. Lastly, the structure inspection mission was performed. This mission involves a complex set of preprogrammed maneuvers. These maneuvers were all performed with the vehicle within two feet of a structure.

In general, the vehicle performed extremely well. The system performed in a very controlled and stable manner. The missions were varied slightly and ran from 16 minutes to 24 minutes. The vehicle was launched from a 6' X 6' hole in a barge and returned to the hole completely autonomously.

A 16mm movie was made of the vehicle maneuvering in and around the structure.

The vehicle was sent out on 18 structure inspection missions and completed 15 perfectly. On two of the missions that it did not complete, a failsafe mechanism shut the vehicle down due to loss of navigation data. Analysis revealed that one path segment chosen for the vehicle on these two missions was such that the vehicle was very shallow (five feet deep) and placed the vehicle in a position atop a transponder such that the vehicle was shadowing its own receiver. The cause of the third incomplete mission has not as yet been determined. The symptoms were that the cycle time of the command computer had somehow slowed down to 4.5 seconds instead of its normal 1.5 seconds. In spite of this



cycle time change, however, the vehicle did complete the mission and did return to the barge.

In summary, the EAVE vehicle system is performing as a very well controlled and stable platform. It can repeatedly perform maneuvers and travel underwater over a preprogrammed course and return to a designated location autonomously.

## 2. EAVE VEHICLE SYSTEM (MECHANICAL) (Figure 11)

### Space Frame

The EAVE structure frame is of welded 6061-T6 aluminum tubing, 1 in. O.D. x .25 in. wall. Supports for the computer and battery tubes are made from 3 x 1 x 1/8 in. 6061-T6 aluminum channel. Fasteners used on the vehicle are stainless steel. Buoyancy counterweights were made from 1 7/8 in. steel hexagonal stock. There are two lengths used, approximately 33 5/16 in. long each and they were welded together with 3/8 x 1 in. bar stock at each end. The dry weight of this unit is 58.1 lbs. The wet weight is approximately 50.7 lbs. in fresh water. With this amount of ballast the vehicle was buoyant by approximately 10 lbs. The addition of 8 lbs. of lead during field tests gave a satisfactory positive buoyancy estimated at 2 lbs.

An improvement which was made to the frame is the fabrication of a set of ballast weights of small values (1 & 2 lbs.) which can be easily added or removed from the vehicle to allow the fine tuning of the buoyancy in the field.

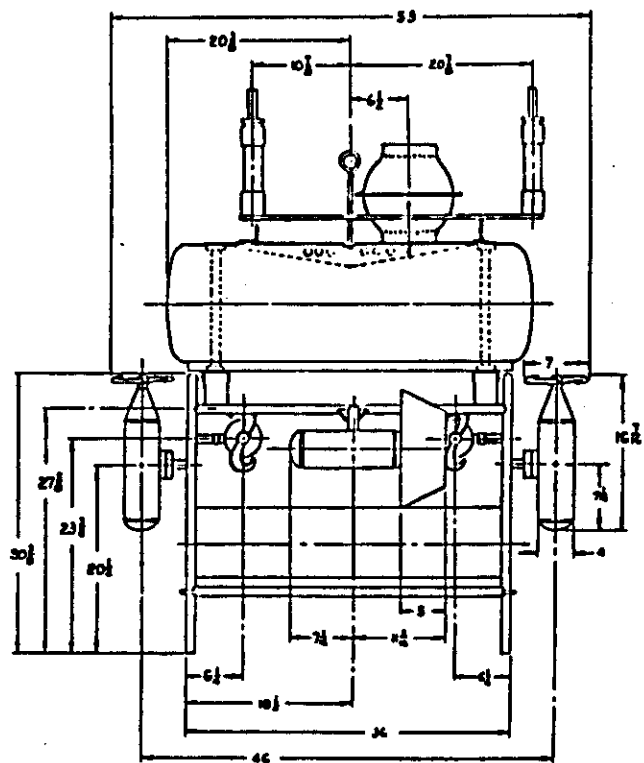
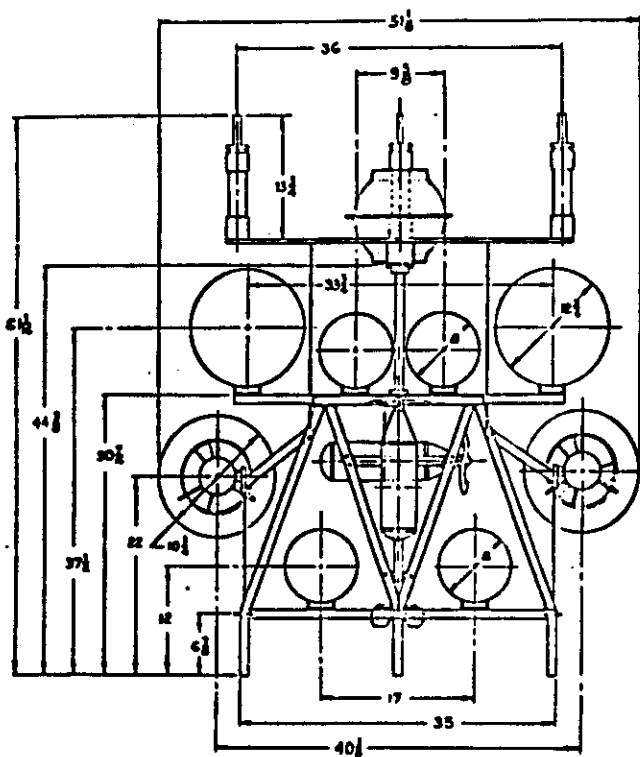


FIGURE 11

MARINE SYSTEMS ENGINEERING LAB	
DATE: 12-18-72	BY: [Signature]
L.A.V.E. DIMENSIONAL OUTLINE	
C-123711	

The only other item that should be improved is the changing of the starboard forward thruster brace from steel to stainless steel.

### Flootation

The floatation tubes are 12 3/4 in. O.D. x 40 3/4 in. lg. The tubes are of three-piece welded construction, consisting of; a cylinder and a torispherical head at each end. The cylinder is 12 in. sch. 40 round 6061-T6 aluminum pipe with a 12.75 in. O.D. and .406 in. wall and approximately 35 3/4 in. long. The torispherical end caps were formed by McCabe fabricators of Lawrence, Massachusetts from .188 in. thick 6061-T6 aluminum disks. The units were seam welded by Dover Machine Shop, Dover, NH.

A stress analysis of the torispherical dome under external pressure yielded a crush pressure of 638 PSI or a depth of 1473 feet of water. Calculations also show that an aluminum cylinder of the above specified dimensions have a collapse depth of 1400 feet.

Each of the buoyancy tubes are held in place by two 1 in.-8 UNC bolts. Each weighs 57 lbs and displaces 160.2 lbs of fresh water for a net buoyancy of 103.2 pounds. The torispherical ends were chosen as a compromise from a spherical or parabolic ends, which would provide the optimum in strength and drag reduction. The torispherical ends were readily available as a standard size press-formed tank head, and presented themselves as the most economical alternative while providing a strength equivalent to the body of the tube, with a substantial reduction in drag.

The weight reduction of the tubes with the elimination of

the flat heads was 13.2 lbs. and the increase in displacement was 0.31 feet or 19.4 lbs. of fresh water, producing a net gain of 32.6 lbs. per tube and 65.2 lbs. total for the vehicle. The increase in buoyancy is counterbalanced with removable weights located at the bottom of the vehicle frame. The excess is intended to allow for the addition of components to the vehicle such as additional batteries or mission related devices.

Calculations show that a 74% reduction in drag was realized through the addition of torispherical ends over the blunt ended tubes used in the past. The magnitude of the force is about .7 lbs. force each at a velocity of 2 ft. per second as opposed to 2.8 lbs. force each for a blunt ended tube. The pressure drag increases with the square of the velocity. (pressure drag =  $\frac{1}{2} C_d \rho V^2 A$ ). The skin friction drag accounts for a very small percentage of total drag. The coefficient of drag for a torispherical head is approximately .2 as compared to .8 for a blunt ended cylinder.

#### Computer and Battery Pressure Cases

The two pressure cases which house the control computers on EAVE are made from 8 in. O.D. x .5 in. wall round extruded 6061-T6 aluminum holobar. The tubes are 36 inches in length and calculations show that the crush depth on this size tube is 10,500 feet. The end caps used on these tubes are 3/4 in. thick 6061-T6 aluminum disks. They have an O ring face seal which is nominally rated at 1500 PSI or a depth of 3465 feet of water.

This rating could be increased with the use of back-up rings on the seal but the limit of the vehicle is 1400 feet which is established by the rating of the buoyancy tubes.

The two battery pressure cases are made from 8 in. O.D. x 375 wall round extruded 6061-T6 aluminum holdbar. These tubes are 36 inches long and are rated for a crush depth of 5,300 feet but the O ring face seals on its 3/4 inch thick end caps restrict this rating to 3465 feet similar to the computer cases.

All end caps at present have flat ends with sharp corners. Drag in the forward and reverse directions on the vehicle could be greatly reduced if we could provide well rounded corners on these end plates. This could present difficulty in mounting the hold down clips on the cap sides, but if possible, the benefits in power reduction required to drive the vehicle could outweigh the effort required to retrofit.

### Thrusters

The thruster motors were manufactured by Minnesota Electric Technology Inc. of Winnebago, Minn. The no load r/m is 1750 when operated at 24V dc. Its peak hp is .22 at 800 r/m drawing about 12.5 amps at that point. The actual load exerted by the propeller on the motor is not known, but under full load the amperage measured during an evaluation of prop Kort Nozzle on the forward thrusters was 12.2. If we relate this amperage to the theoretical performance curve supplied by Minn. Electric it would indicate that we are at the peak hp available and are operating at about 800 RPM. The forward thrusters are equipped with a 7 1/2 in. dia. three blade propeller with a 10 inch pitch. The

prop and the Kort Nozzle were bought as parts from a Diver Propulsion Vehicle 01-1002MK-11 manufactured by Farlon Oceanic Industries, 14275 Catalina Street, San Leandro, CA 94577 (415-352-5001). The Kort Nozzle was modified by MSEL to adapt to the thrusters and the outside was filled with a syntactic foam to conform it to a true Kort Nozzle shape (foil.)

The vertical and horizontal thrusters do not have Kort Nozzles and are equipped with a 7 inch, two blade prop with a 5 inch pitch. The prop was purchased from Minn. Kota Inc., 201 N. 17th Street, Moorehead, Minn. 56560 (507-345-4623) under Part No. 03308. The prop was used on an electric trolling motor.

Tests on the thrust of both props were conducted. Results of these tests showed that the average peak thrust was about 7 lbs. with the two blade Minn. Kota prop in the forward direction and 4 lbs in reverse.

#### Temperature Effects on Thruster Performance

Previous experience had shown that at reduced temperatures, in the 35 - 40 degree F range, the thrusters suffered an extreme loss of shaft speed and therefore performance. This unacceptable phenomenon was attributed to the increasing viscosity of the transformer oil being used for pressure compensation. The oil was therefore replaced with dow corning #200 fluid, a clear silicone fluid which exhibits a relatively flat viscosity slope over the expected operating temperatures.

The test consisted of the thruster being submerged, in a vertical position, up to its shaft seal in a water bath. The vehicle's batteries were used to supply a constant voltage

directly to the thruster. The shaft speed (rpm) of the operating thruster was monitored as the temperature was gradually reduced, using ice, down to approximately 1 degree C and then allowed to rise again. Temperature and shaft speed were recorded at one minute intervals. The data shows no loss of shaft speed which can be attributed to the effects of temperature changes. The variations which occurred are believed to be only the random fluctuations observed previously in the performance tests. The lack of temperature related reductions in shaft speed indicates that the Dow Corning fluid will correct the problem previously encountered at reduced temperatures.